Spatial Variability and Robust Interpolation of Seafloor Sediment Properties Using the SEABED Data Bases

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LONG-TERM GOALS

This project is a collaborative effort with C. Jenkins at the Univ. Colorado. The long-term goals are to: (1) advance the understanding of the spatial variability of seabed properties as a function of geologic environment; (2) develop robust means of interpolation in the presence of uncertain data, (3) provide for the estimation of uncertainty in the interpolation at unsampled locations, and enable investigation of optimal survey design to minimize uncertainties; and (4) publish a computational/database structure capable of producing seafloor maps of wide geographic extent, for multidisciplinary use - in global change issues, defense, engineering, and ecology.

OBJECTIVES

The US Geological Survey, in collaboration with Chris Jenkins of INSTAAR/Univ. Colorado, is nearing publication of a large data base of seabed sedimentary properties in US coastal and shelfal waters. Dubbed "usSEABED" (http://walrus.wr.usgs.gov/usseabed; USGS publications DS 118 (Atlantic), 146 (Gulf of Mexico) and 182 (Pacific)), the data base is a compilation of available records of sedimentary data from seafloor samples, cores, and visual observations. Over 120,000 independent seafloor mean grain size measurements are included, along with many other data types. This work is part of a larger effort to develop a world-wide data base (collectively, the "dbSEABED" data bases), which continues to enlarge every year with additional records (http://instaar.colorado.edu/~jenkinsc/dbseabed).

The comprehensive dbSEABED data bases provide a new and unprecedented opportunity for advancing Navy interests related to the acoustic response of the seafloor: (1) they will enable the creation of maps of seafloor sedimentary properties over areas and at a level of detail previously unobtainable with single campaign efforts; and (2) they will enable investigation of the variability of sedimentary properties, which is a critical factor in assessing uncertainty in acoustic detection, over a wide range of environmental conditions. However, the highly heterogeneous nature of these records present important challenges in data handling. The most significant issue involves the measurements of mean grain size either by "extracted" or "parsed" methods. Extracted measurements are derived from analytic methods of computing the grain size histogram, such as sieves, settling tubes or diffractometry. Such measurements tend to be very precise. Parsed measurements of mean grain size are derived from a calibrated conversion of a word-based description of sediments (e.g., sand, fine

Report Documentation Page

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2006		**00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Spatial Variability and Robust Interpolation of Seafloor Sediment Properties Using the SEABED Data Bases	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
University of Texas,Institute for Geophysics,4412 Spicewood Springs Rd., Building 600,Austin,TX,78759	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

sand, mud, muddy sand, gravelly sand, etc.). Although less precise, such measurements provide the only comprehensive coverage in many regions. The extent to which these two forms of measuring mean grain size are compatible is a critical outstanding and a consequent objective of our work. Observational bias represents a second significant issue. Bias is most prominently manifest in the inclusion or exclusion of coarse fraction (e.g., shell hash), depending on the needs of the observer. Extracted measurements appear more likely to exclude the coarse fraction, which are important to acoustic considerations.

Through a collaborative ONR-funded project, the USGS is making a draft version of the usSEABED data base available to the PIs to address the following objectives: (1) Determine geostatistical variability of seafloor grain size across the usSEABED data base, and classify by environment, and (2) Determine a method for making the best possible seafloor sediment maps from a noisy, heterogeneous data set such as usSEABED.

APPROACH

Goff's primary task for this project is statistical analysis of grain size data and developing a tool for correcting noisy data through resampling. The latter task was described in the previous progress report. Here I describe accomplishments regarding seabed variability investigations based on the usSEABED data base (Figure 1; Jenkins 1997, 2002; Williams et al, 2003).
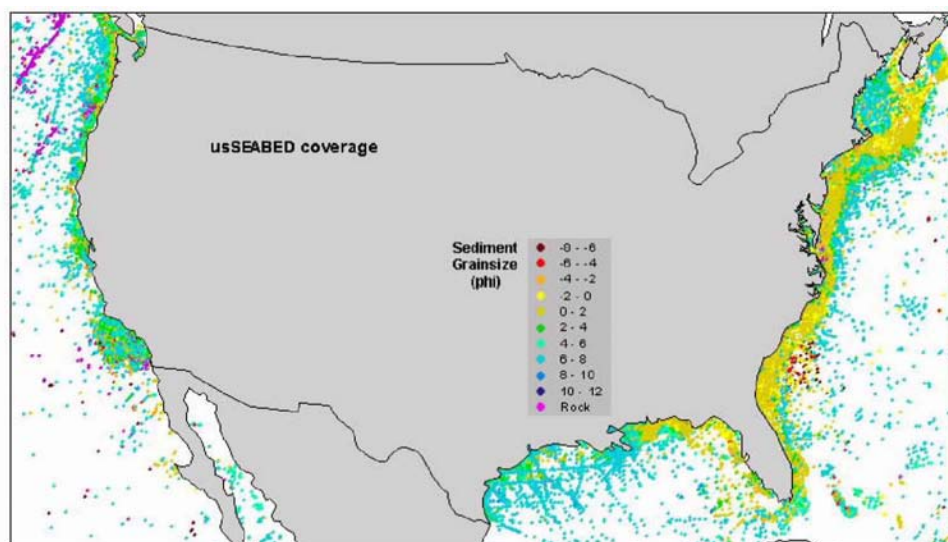

Figure 1. Locations of data contained within the usSEABED
data base, color coded by the mean grain size entry

Statistical measures are determined within domains determined by geographic setting and data sufficiency (statistical measures cannot be determined from a region with too few samples). ArcGIS functionality is employed to select regions for analysis and subset the data for analysis. We determine statistical measures primarily through analysis of semi-variograms constructed for each domain using a binning method (e.g., Goff et al., 2002; 2004). The semivariogram quantifies the variance of differences as a function of horizontal scale, and is related straightforwardly to both the covariance function and the power spectrum. The semivariogram functionality allows us to estimate the accuracy with which a value at an unsampled location can be predicted given the sample values at other

locations. This information is critical in determining how well we can interpolate or extrapolate data in making maps. We are also able to distinguish through this analysis the portion of the total variability that is associated with real sediment variability, and which is associated with measurement uncertainty, or "noise." The latter is "white" in character (equal power among all wavelengths), whereas the former is "red" (decreasing power at shorter wavelengths). This information is needed for application of noise reduction techniques. These functions are then inverted for a best-fit von Karman model with noise (a recently-developed software capability), which provides parameterization of the noise variance, property variance, decorrelation length scale and, if data density warrants, the fractal dimension. The noise variance characterizes the random uncertainty in the data. The property variance characterizes the overall level of variability of the sedimentary property being measured, distinct from the uncertainty-derived variability. The decorrelation length is a measure of predictability as a function of distance: a long decorrelation scale implies greater predictability of a value at an unsampled location given proximal samples elsewhere. The fractal dimension is a measure of small-scale "roughness" in the variability; a lower fractal dimension also implies greater predictability.

WORK COMPLETED

The primary accomplishment of the PI thus during the past fiscal year has been to complete the development of the methodology for deriving statistical properties from a point data base (described above), and application of these methods to the usSEABED data base. Results for FY2005-2006 are described below.

RESULTS

(1) *Progress in understanding the quantitative relationship between parsed and extracted data.* Two methods were employed to investigate the relationship between parsed and extracted measurements of mean grain size. The first was a deterministic comparison of nearest neighbors of the two types of measurements (<200 m apart). Nearly 7000 such comparisons were available in the usSEABED data base (Figure 2). The second was a comparison of the statistical behavior for the extracted and parsed measurements, computed from 10 regions with good coverage of both data types (Figure 3). The average mean grain size of the area was computed, and the empirical semi-variogram was inverted for parameters describing the uncertainty (noise variance), mean grain size variance, and decorrelation length scale. Our principal findings are that parsed values, in comparison to extracted values, (1) tend toward more coarser measurements (up to ~2 phi, on average), (2) may exhibit greater levels of variance in mean grain size, particularly for finer sediments, and (3) have greater uncertainty (i.e., are noisier). The first two findings may, in large part, be due to the possible tendency of extracted measurements to exclude coarse material. We also found, however, that parsed values are limited to mean grain size estimates of <7 phi, whereas extracted values can range to >10 phi. The third finding is expected, given the nature of the parsed estimations. Decorrelation scales are generally identical between the two types of measurements, indicating that either can provide fair estimates of spatial variability.
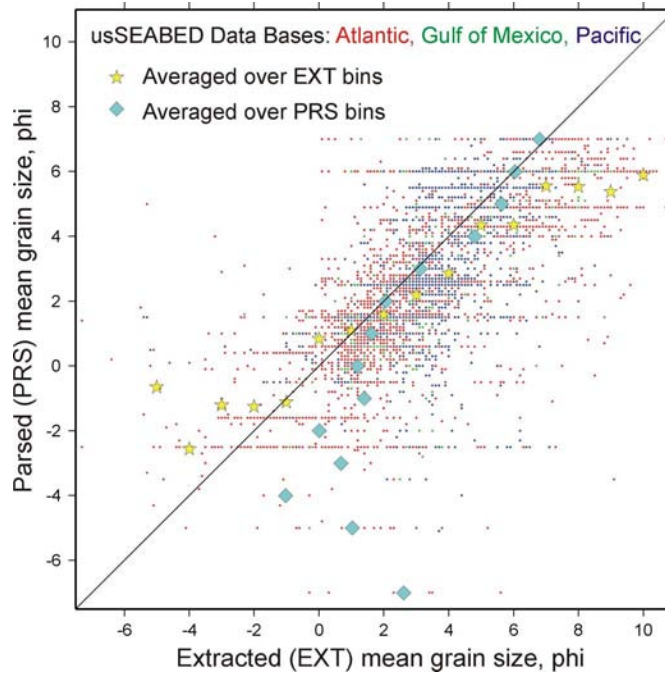
Figure 2. Parsed versus extracted mean grain size measurements at ~collocated sample locations (within 200 m) over the full usSEABED data base. Over most of the population, there is a tendency for the parsed measurements to have coarser measurements (lower phi values), possibly due to a prompensity in extracted measurements to exclude coarse fraction.
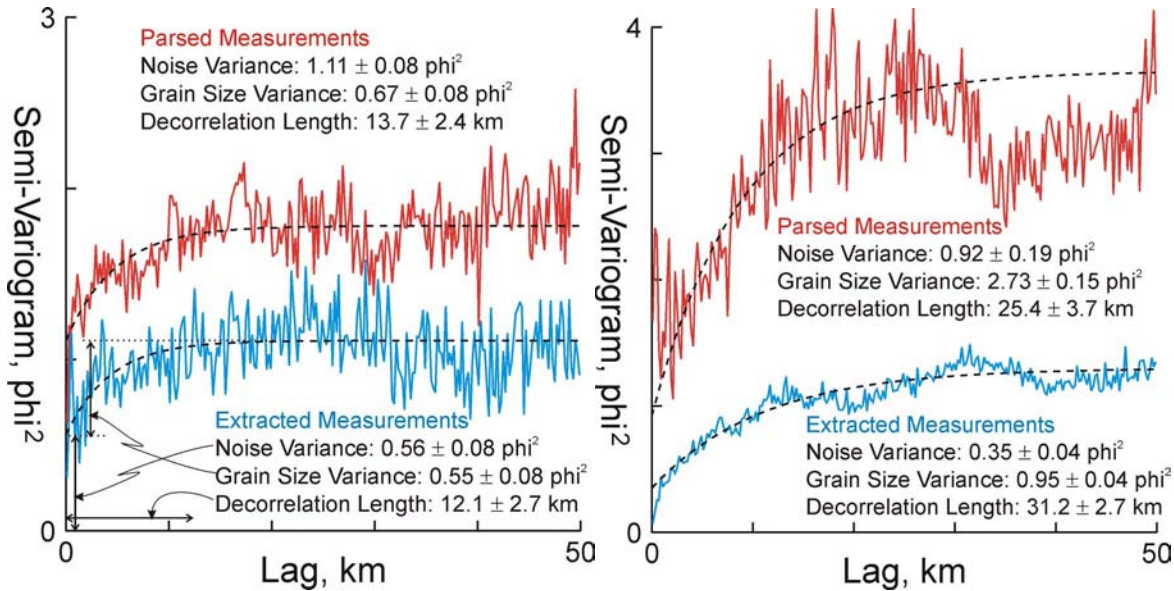

Figure 3. Two examples of semivariogram statistical analsys of both parsed and extracted mean grain size measurements for two different continental shelf regions: the mid-Atlantic bight 0-20 m (left), and the Pacific, Gulf of Farallons (right). The two examples illustrate the two primary observed behaviors. In the left panel, the parsed and extracted semivariograms have the same functional form, but offset due to greater uncertainty (noise variance) in the parsed measurements. In the right panel, the parsed measurements also exhibit greater grain size variance, although the decorrelation lengths are similar.

(2) *Progress in characterizing geostatistical variability for the usSEABED data base.* Data subset areas were selected on the Atlantic, Pacific and Gulf of Mexico continental shelves of the US to examine sediment variability by region. These areas were selected based both on regional setting and data coverage. A target data size of ~1000 samples (either parsed or extracted) was sought for each area, in order to obtain a well-resolved empirical semivariogram. Inverting these semi-variograms yielded mean grain size variances (Figure 4) ranging from <0.2 phi^2 to >4 phi^2 (average 1.6 phi^2) and decorrelation lengths (Figure 5) from <2 km to >50 km (average 19 km). Interpretation of these results is underway, but we are investigating a working hypothesis that the decorrelation scale is determined by a balance between sedimentary inputs to the shelf (which tend toward larger scales) and oceanographic reworking (which tends toward smaller scales).
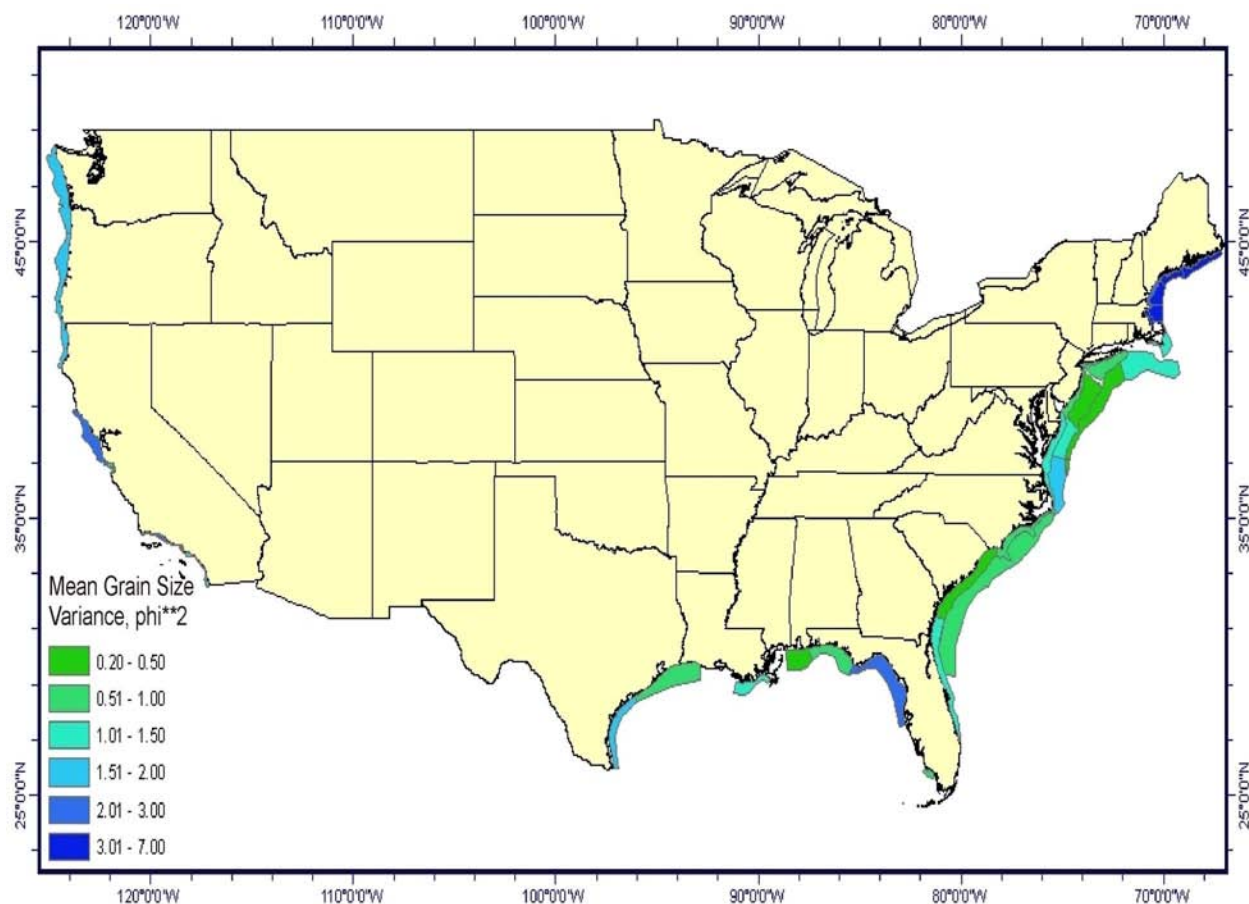

Figure 4. Mean grain size variance derived from semivariogram analysi of the usSEABED data base (unpublished).

IMPACT/APPLICATIONS

This project could provide a major advance in marine science, a set of reliable methods which transform point-site seabed data into griddings that will be useful across oceanographic disciplines, sediment transport, acoustics, habitat, wave-energy generation. Our work will result in a set of software tools that will be open source, and available for inclusion any existing software packages. These tools could be of importance to the Navy, particularly in dealing with areas with sparse data,

such as "denied" areas. In particular, an understanding of the relationship between environmental parameters, geologic setting and spatial variability could provide an ability to predict the amount and spatial scales of seabed variability using a parameterized semi-variogram model. This functionality provides a basis upon which to predict seabed parameters at unsampled locations, and to assess the uncertainty in that prediction. Such an understanding will have important implications for assessing acoustic prediction uncertainty. Furthermore, the semi-variogram model can be used to investigate optimal survey design, should it be possible to conduct limited sampling in denied areas via covert means (e.g., AUV's).
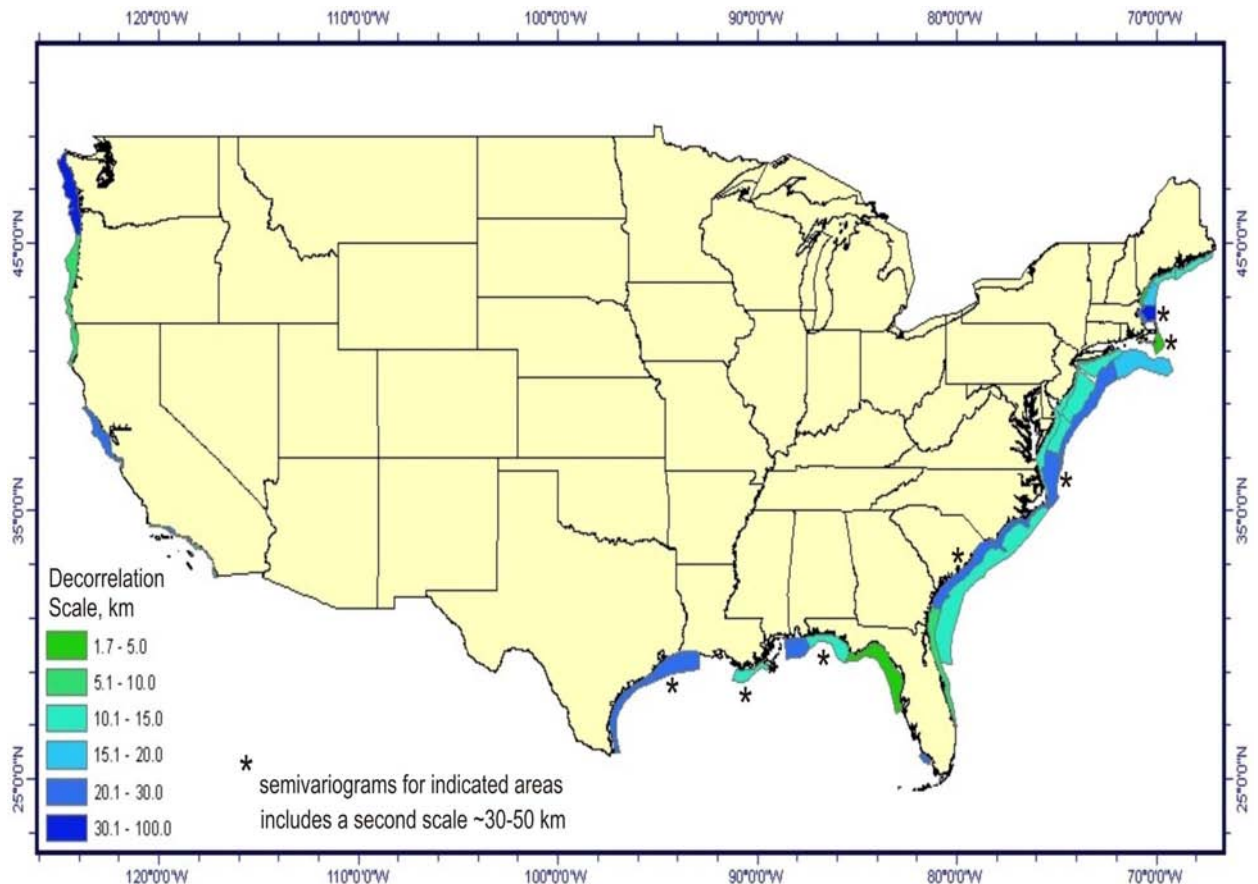

Figure 5. Decorrelation length scales derived from semivariogram analysis of the usSEABED data base (unpublished).

RELATED PROJECTS

This work is not presently linked to any other programs, but could prove useful to ONR programs such as the Ripples DRI and the Shallow Water Acoustics '06 experiment, which will make use of interpolated point data related to seabed properties.

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